Image Referencing and Scene Computation for Indian Remote Sensing Spacecraft

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Abstract

The paper provides scene computation procedure adapted in various Indian Remote Sensing missions. In order to provide a comprehensive view, description is provided on orbit selection procedure, the concept of image referencing scheme, different reference frames and transformations among them. Definitions of basic terms are provided with diagrams. Finally, the scene computation procedure is provided.

Overview

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1. Introduction

The operational era of Indian Remote Sensing has started since the launch of IRS-1A. The payloads of spacecraft have largely been optical. In conjunction with the camera characteristics and mission requirements, the orbit selection process caters to a number of mission aspects, such as repeatability, near re-visit, across track overlap of the reference camera swath on ground, etc. Section 2 provides a brief outline of orbit selection in relation the subject of discussion. Given payload characteristics, in order to annotate the imaging region on the ground the coordinates on the ground are computed by geometrical methods, making use of accurate spacecraft position and velocity information and first approximation of asphericity of the earth. The computations are carried out by grouping together a number of scan lines. For the sake of choosing an imaged region for data product generation as well as storage of information related to imaged regions, it is necessary to group such scans meaningfully. The image referencing scheme provides such a meaningful grouping. Such groups of lines are termed as scenes. The scenes are defined in terms of number of scan lines and pixels. Section 3 provides a discussion on the factors considered in generating, image referencing schemes and outline of a typical scheme.

Image referencing scheme, scene definition and definitive spacecraft orbit and attitude parameters provide the basis for scene computations. The scene computation and the modelling aspects are provided in Section 4. Section 5 and Section 6 contain acknowledgements and references respectively.

2. Outline of Orbit Selection Process

The selection of orbit is vital for optimal utilization of a mission (Raja Singh, C.K., et al, 1977). The orbit is characterized by six orbital parameters, viz., semi-major axis (a), eccentricity (e), inclination (i), argument of perigee (ω), Right Ascension of Ascending Node (Ω) and Mean Anomaly (M). The definitions are provided in Fig.2.1 and 2.2. Required shift of the orbital trace on the ground (ground trace) with reference to previous day, the no. of days after which the same region to be revisited (repeat cycle), no. of days after which a ground trace falls close by (near-revisit) are achieved by an appropriate combination of a, e, i and the effect of oblateness of the earth. The orbit selection is strongly associated with onboard payloads and vice versa. Table-2.1 provides the orbital parameters and repeat characteristics of some Indian remote sensing spacecraft. The ground traces generated by nominal orbit for a full cycle constitute paths.

3. Brief Overview of Image Referencing Scheme

A number of perturbative forces act on the spacecraft in orbit, such as, oblateness of earth, atmospheric drag, luni-solar attraction and solar radiation pressure. Under their influence the selected nominal orbit undergoes short-term and long-term variations. Albeit, operationally, the orbit is controlled to remain within pre-decided limits of the orbital elements, it does deviate from nominal ground trace pattern. In view of this, a set of nominal ground trace paths is identified. The nominal ground traces are termed as paths. Further, along the paths a set of points is identified. The points are identified to be on the same latitude irrespective of the path they belong to. These points are termed as rows. The set of nominal paths and rows constitute a “referencing scheme”. There exist different methods to select latitude of rows.

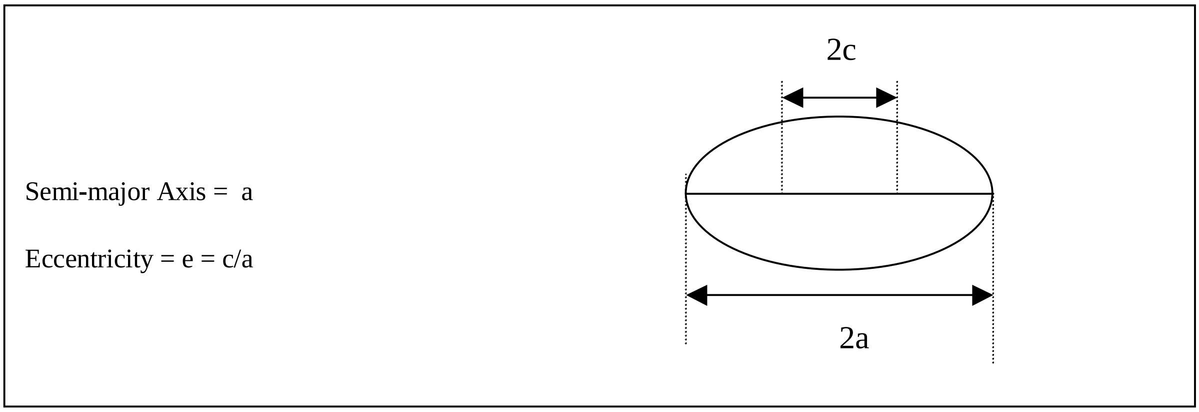
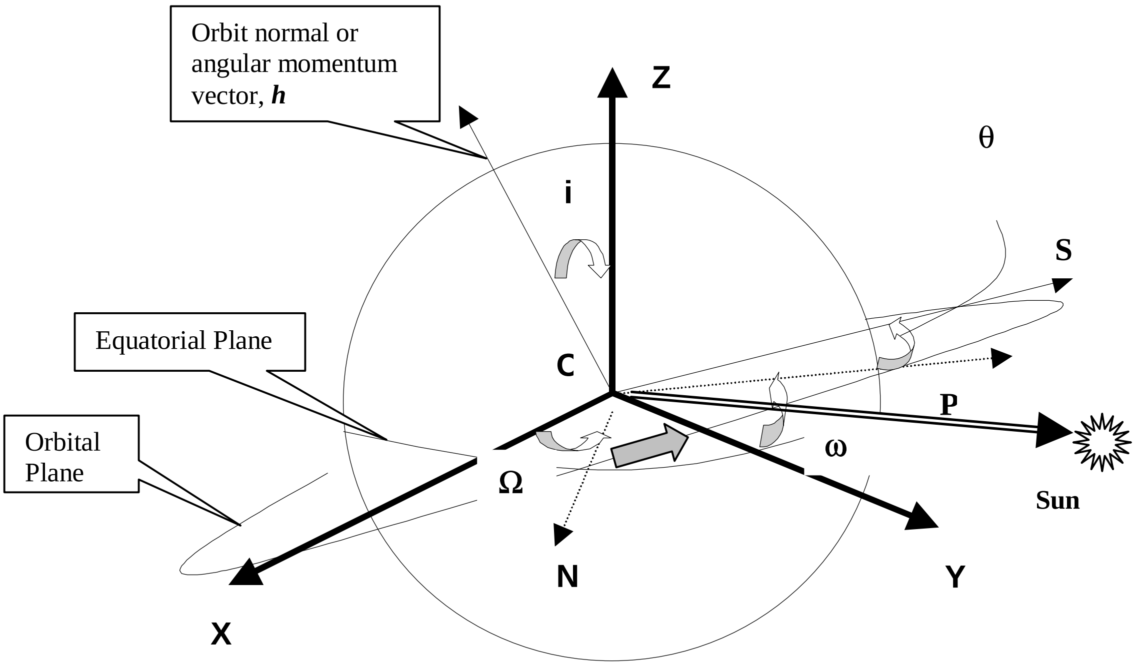


Fig – 2.1 Orbital Elements – shape and size



X,Y,Z – Earth Centred Inertial Coordinate System

N – Ascending node, point of intersection between equatorial and orbital planes, when spacecraft is north bound

P – Perigee point

S – Spacecraft

θ – True anomaly, related to Eccentric Anomaly (E). E and M are related through Kepler's equation

Fig 2.2 Definition of orbital parameters

Table-2.1: Orbital parameters and repeat characteristics of some Indian remote sensing missions

Satellite Name	No. of revolutions per day	Orbital Parameters			Repeat Cycle		Near revisit	
		'a' (km)	'e'	'i' (deg)	No. of days	No. of paths	No. of days	No. of paths
IRS-1A/ IRS-1B	$13\ ^{21}/_{22}$	7282.277	0.002	99.028	22	307	1	1
IRS-1C /IRS-P6 /IRS-P3	$14\ ^{5}/_{24}$	7195.114	0.0011	98.0	24	341	5	1
IRS-1D	$14\ ^{8}/_{25}$	7157.512	0.007	98.534	25	358	3	1
IRS-P4	$14\ ^{1}/_{2}$	7098.096	0.0011	98.284	2	29	-	-
IRS-P5 (Carto-1)	$14\ ^{103}/_{126}$	6996.132	0.0011	98.872	126	1867	11	1

Selection of Rows

A remote sensing spacecraft with optical payloads may have one or more optical payloads. Out of the payloads available onboard, one of the payloads is chosen as reference for identification of rows and the scene framing. The framing of the other scenes is carried out in relation to the reference payload. Further, the line integration time is a function of ground track velocity. There are basically two approaches for selection of rows (Nagarajan, N et al), viz., (a) identifying the rows in the intervals of fixed latitude and (b) identifying the rows in the intervals of fixed number of lines. Because of a number of advantages of scheme (b) such as uniformity of along the track and across the track overlaps irrespective of altitude variations throughout the mission, it is chosen for all the IRS referencing schemes. Table-3.1 provides a list of reference payloads for some missions and the respective scene sizes.

Table 3.1

Satellite Name	Reference Payload	Scene size	
		No. of scan lines	No. of pixels
IRS-1A/1B	LISS-I	2400	2048
IRS-1C/1D	LISS-III	6000	6000
IRS-P4	OCM	6026	3730

The requirements on referencing scheme vary witch each mission objectively. Following section provides a brief description on varying concept of referencing scheme.

Changes in the concept of Reference Scheme

For most Indian remote sensing missions, a fixed referencing scheme is adapted. However, with the changes in the mission objectives, the fixed schemes are being replaced by framing a fixed number of lines starting from the payload switch-on. Each of these methods has its relative advantages and disadvantages. The fixed schemes are useful for relatively small repeat cycles, e.g., less than a month, as the mission objectives would have demanded. For such missions, the imaging is repeated after a fixed period of time. The scheme has advantages such as ease of comparative studies of same scene or a region, across cycles, easy to store in information management database and help easier mosaicing of larger area across different periods of the mission life. Non-fixed schemes are useful in imaging ground regions in different directions, as is possible in case of step and stare missions, stereoscopic imaging and paintbrush type of imaging, etc.

4. Scene Computation

A scene is associated with the payload under consideration. As mentioned previously, a scene consists of a group of scan-lines, which is so chosen to provide along track overlap between successive scenes. Each of scan line consists of a number of CCD elements, hereinafter referred to as pixels. The scan lines and pixels is payload dependent.

The scene computation relates to computation of centre and corner coordinates of the scene and the time of their occurrence. This information is, operationally, attached to sub-sampled browse images. The browse images are used to identify the regions for product generation. The coordinates of latitude and longitude are provided as geodetic coordinates.

The spacecraft is controlled to remain within pre-specified limits with reference its three axes viz., Yaw (towards earth centre), Pitch (negative orbit normal, refer Fig 2.2) and Roll completing the right-handed system. The Roll, Pitch and Yaw form the attitude of the spacecraft. Thus, when the errors about the three axes are null, the yaw axis forms the look vector direction and would be pointing towards the centre of the earth (Point 'O' in Fig 4.1).

In order to compute the look vector direction, transformations among a number of reference frames are carried out. The following sections provide the descriptions and definitions of the necessary background terminology prior to the discussion on transformations.

4.1 Reference Frames for Scene Computation: A number of coordinate systems are involved in scene coordinates computation. They include,

- True to date coordinate system
- Earth Centred Earth Fixed system
- Body Centred System
- Master Reference Cube system (MRC)
- Payload Reference Cube system (PRC)
- Camera Payload coordinate system

Operationally, spacecraft position and velocity at given time, termed as "state vector" is statistically estimated based on range and angles observations on the spacecraft. The estimated state vector is provided to true-to-date coordinate system. The look-direction depends the state vector and determined spacecraft attitude.

In the Earth Centred Inertial (ECI) coordinate system, X-axis is directed towards first point of Aries and Z-axis is towards North Pole. The fundamental plane is the equatorial plane. Y-axis completes the right-handed system. The ECI system is defined at some reference time point. The true-to-date system accounts for precession and nutation as on the given time. The Earth Centred Earth Fixed (ECEF) system consists of the equatorial plane as the fundamental plane. The X-axis passes through the Greenwich meridian (zero longitude) and Z-axis coincides with that of ECI frame. Y-axis completes the right-handed system. The transformation between true-to-date system and the ECEF system is by means of sidereal angle in which the precession and nutation components are accounted. The following equation provides transformation:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_G = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_I$$

The Body centred system is given by the Yaw ($\hat{Y}$), Roll($\hat{R}$) and Pitch ($\hat{P}$). They are dealt with previously in Section 4. Let $\hat{r} = (r_x, r_y, r_z)$ and $\hat{v} = (v_x, v_y, v_z)$ be unit vectors of position and velocity, in true to date system, respectively.

$$\hat{h} = \hat{r} \text{ X } \hat{v} \;/\; |\hat{r} \text{ X } \hat{v}|$$

$$\hat{T} = \hat{h} \text{ X } \hat{r} \;/\; |\hat{h} \text{ X } \hat{r}|$$

$$\hat{Y} = -\hat{r}$$

$$\hat{R} = \hat{T}$$

$$\hat{P} = -\hat{h}$$

Onboard the spacecraft there exists a Master Reference Cube with reference to which all the payloads are mounted. All the mounting alignments are measured with reference to MRC. In the absence of misalignments of camera payload, the look direction coincides with the Yaw vector. In general, in the absence of misalignments the body coordinate system coincides with that of MRC.

The payloads are mounted with reference to Payload Reference Cube (PRC). The desired mounting angles are measured with reference to PRC. In the event of no misalignments caused either by mounting or otherwise, PRC would coincide with MRC.

The scene framing activity results in computing the coordinates of imaging points on the surface of the earth, the shape being approximated by a reference ellipsoid. The coordinates are provided as geodetic coordinates. The following section provides a brief description on geodetic coordinates.

4.2 Geodetic Coordinates: The definitions of geocentric and geodetic coordinates are provided in Figure 4.1. Given spacecraft, S, the look vector in the ideal conditions is towards Earth's center. The vector **SO**, intersects reference ellipsoid at the point P. Angle β is the acute angle measured from the x-axis **OX** to the vector **OS** is known as geocentric latitude. Assume a tangential plane perpendicular to the ellipsoid at point P. The vector **PQ** is perpendicular the tangential plane at P. It intersects the X-axis at **Q**. The acute angle measured from **OX** to **QP** is defined as geodetic latitude, ϕ.
The set (ϕ, λ, h) form the geodetic ellipsoidal coordinates. They related to Earth Centred Earth Fixed (ECEF) coordinates (x,y,z) by means of the following equations (Carlson, Neal A., 1980):

$$\rho = R_a / \{1 - e^2 \sin^2 \phi)^{1/2}$$

$$x = (\rho + h) \cos\phi \; \cos\lambda$$

$$y = \{(1 - e^2)\rho + h\} \sin\phi$$

Whereas the computation of x,y,z given geodetic coordinates is performed directly, computation of geodetic coordinates given, x,y,z cannot be performed directly. It requires an iterative solution (Escobal, P.R., 1975 & Carlson Neal A., 1980).

where, ρ - radius of curvature of ellipsoidal surface

R_a, R_p – Equatorial and polar radii of the reference ellipsoid

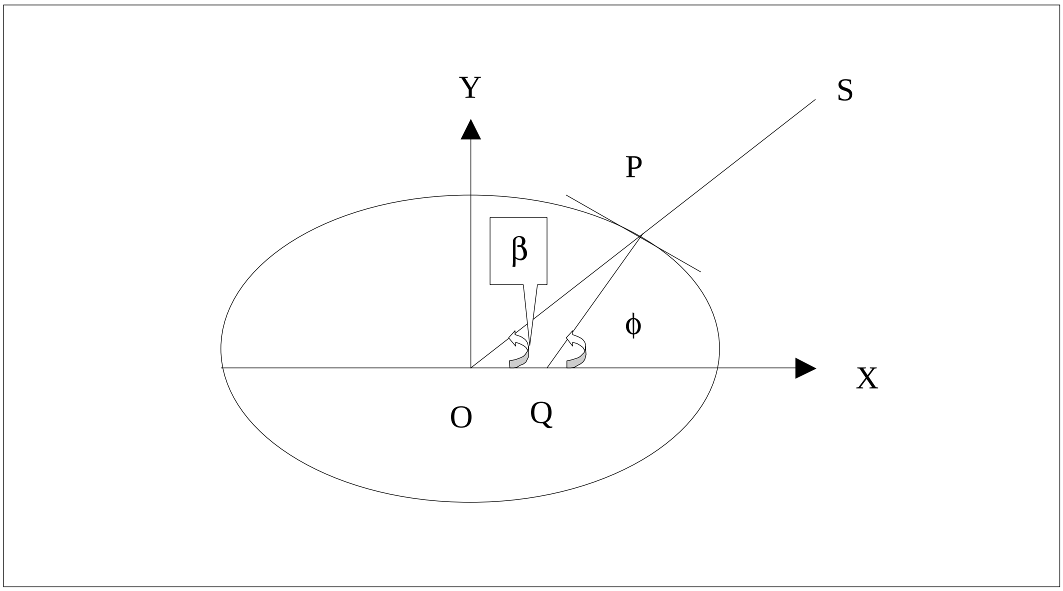


Fig 4.1 Geocentric and Geodetic Coordinates

e = $(1 - R_p^2 / R_a^2)^{1/2}$, eccentricity of the reference ellipsoid

h = height above the reference ellipsoid

The spacecraft attitude information is vital for accurate computation of scenes. The following section provides different ways of accounting attitude. The details of terms such as step and stare imaging, paint-brush imaging, factor affecting spacecraft attitude are not dealt in the current paper as it is beyond the scope of the current paper. However, the scene computation methodology is valid even for the other types of imaging.

4.3 Usage of Spacecraft Orientation Information for Scene Computation: It is important to consider space-craft orientation information or spacecraft attitude, for scene computation. There are two basic approaches in using this information operationally. Firstly, compute the scene coordinates without considering attitude and then correct for the coordinates for the change in the attitude. Secondly, use the spacecraft attitude information in arriving at the coordinates. This depends on the nature of imaging too. For example, in case of IRS-1C and IRS-1D, the imaging is carried out at the desired direction, which deviates from the plan, only by attitude. However, in case of step and stare or paintbrush type of imaging, the imaging is carried out by a pre-decided profile. The actual profile might deviate for variety of reasons, the details of which are beyond the scope of the current discussion. Because of this, it would become necessary to account of attitude first before scene computation, in addition to the other information.

4.4 Scene Computation with Camera Tilt: The camera payloads onboard the remote sensing missions may have either a fixed bias for certain long duration of time, or mechanically steerable, or entire spacecraft could be subjected to attitude-maneuvering to image a desired region. The procedure described below is valid for all such cases.

4.5 Scene Computation Procedure: Firstly the framing procedure is explained in case of fixed referencing scheme and it is extended to other types of framing subsequently.

A scene is characterized by a fixed number of scan lines, say, n. Each scan line would consist of k pixels. Albeit, it is possible to compute the ground coordinates of every pixel, the scene framing is restricted to computing the scene centre and corner coordinates only (Ref Fig. 4.2 and Fig 4.3). The reference scene centre latitude are as defined by referencing scheme. Following is the procedure to compute the scene coordinates:

- Given spacecraft position and velocity, compute the time at which a scene centre latitude is imaged by the spacecraft
- At this time instant, compute spacecraft look vector using the following steps:
  - ➢ Compute unit vector directions of R,P,Y from the given state vector in true-to-date system as described in section 4.1
  - ➢ Transform unit vector look direction (Y) to Y' after accounting for determined spacecraft attitude.
  - ➢ Transform unit vector look direction (Y') to Payload cube, accounting for measured alignment angles between MRC to Payload cube. The results is stored in 'a'
  - ➢ Transform 'a' to Payload frame, accounting for measured alignment angles between Payload cube to Payload frame. Store the result in 'b'
- Compute the point of intersection of vector 'b' with that of equation of reference ellipsoid. The coordinates are converted to geodetic coordinates and printed. This provides scene centre coordinates.

The scene start coordinates are obtained by marching in time equivalent to the number of scan lines amounting to half the scene. The corner coordinates are obtained by considering field of view equivalent to the number of pixels and following the above procedure.

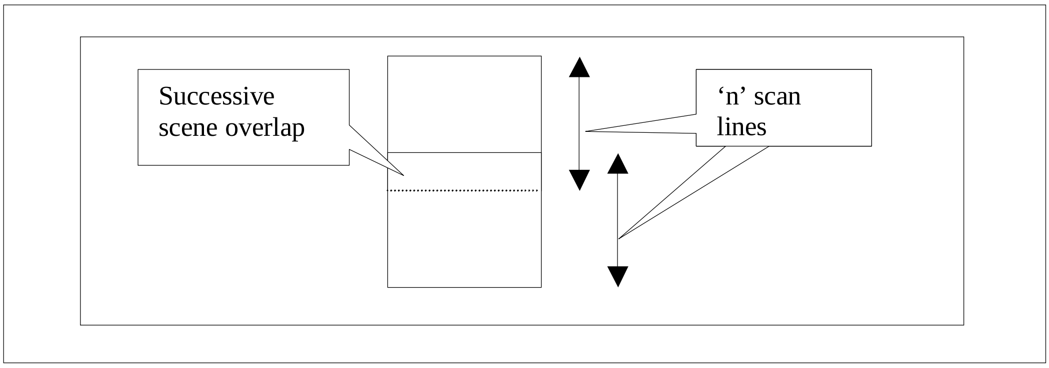
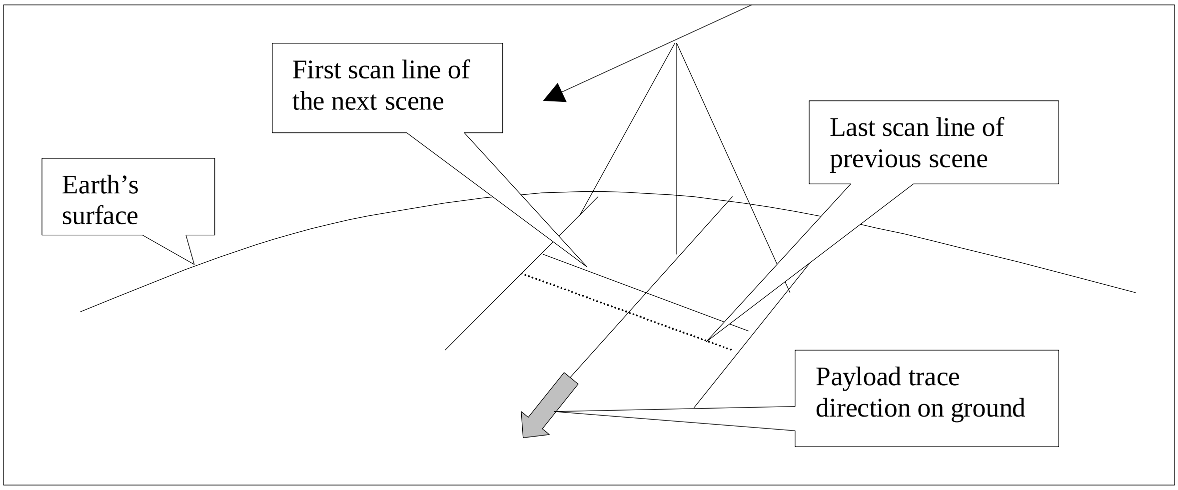


Fig 4.2 Typical Scene Layout



4.3 Typical Imaging Scenario

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